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REVIEW

Freshwater bivalves rearing: a brief overview

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Abstract Freshwater bivalves farming is principally focused on freshwater pearl production in Asia and conservation aquaculture in USA while in Europe is almost completely unknown. High larval mortality is considered the bottleneck in freshwater bivalve larval rearing and methods currently used in marine bivalve larval rearing can be transferred in freshwater mussels. It is likely that probiotics and aquatic microbiology will play a key role also in freshwater bivalves larval rearing. Alternative applications of freshwater mussel rearing should be studied in deep in the future as integrated productions, bioindication projects and utilization of freshwater mussel meal as potential source for fish feeds. The aim of this review is to give a description of potential applications for freshwater bivalve rearing and possible future perspectives.

Keywords Bivalves · Aquaculture · Probiotics · Larval nutrition · Integrated aquaculture · Mussel farming

Introduction

Considering their large size, freshwater farmed bivalves belong mainly to Unionidae (Bivalvia: Unionidae Rafinesque, 1820) that is the largest family of freshwater bivalves in the world. Unionids have a world-wide distribution with very high species diversity in North America, in China and South East Asia (Karatayev et al. 2007; Bogan 2008; Bogan and Roe 2008). In this moment, freshwater bivalves farming is mainly focused on freshwater pearl production in Asia and conservation aquaculture in USA, moreover in Southern India freshwater mussel are reared for human consumption (FAO 1986; Chakraborty et al. 2008). In Europe freshwater mussel farming is almost unknown and freshwater bivalves are investigated principally for the relation with the diffusion of non-native species, as zebra mussel (*Dreissena polymorpha*) and Chinese pond mussel (*Synanodonta woodiana*). The presence and diffusion of non-native species represents a serious threat for US freshwater bivalves as already stated by a letter to Nature in 1997, “Freshwater unionid clams in North America have been virtually eliminated from waters that are colonized by zebra mussels” (Nichols and Wilcox 1997). Considering their crucial role in the freshwater ecosystem and the decline of natural populations (Bogan 1993; Lydeard et al. 2004), several researches are currently carried out in conservation of freshwater mussel and larval rearing is still the main problem to be solved. The use of antibiotics, disinfection, probiotics and immunostimulants during the larval rearing has solved larval mortality in marine bivalves (Nicolas et al. 2004; Prado et al. 2010). Considering the literature in conservation aquaculture, freshwater

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bivalve farming and bivalve artificial nutrition, the aim of this paper is to give a description of potential applications for freshwater bivalve rearing and possible future perspectives.

The importance of reproduction and larval rearing in fish conservation aquaculture

Conservation aquaculture pertains conservation and recovery of endangered aquatic species. It involves working with natural aquatic populations thus transferring the standard aquaculture techniques with the aim to recover them or improve their natural diffusion. In some areas of the world freshwater mussel conservation represents a crucial aspect of freshwater ecosystem conservation, for instance in the USA where up to 70 % of all freshwater mussels are endangered species (Diana 2009). The commercial and recreational value of some fish species has enormously stimulated researches in fish and crayfish conservation aquaculture, while freshwater bivalves conservation has been investigated in very small extent. Fish conservation aquaculture is primarily focused on habitat improvement, biological cycle and natural reproduction and secondarily on population genetic status characterization, to preserve natural genetic diversity. Nowadays in freshwater ecosystems these techniques of conservation aquaculture are very well established and consolidated for fish species, as the case of European salmon (*Salmo salar*) (Stefansson et al. 2003; Maynard et al. 2004), native Salmonids in Italy (Sicuro et al. 2006), in Austria (Lahnsteiner et al. 2009), Danubie salmon (*Huco huco*) in Romania (Jungwirthi et al. 1989), sturgeons in Europe (Steffens et al. 1990; Bronzi et al. 1999) and in Russia (Secor et al. 2000; Chebanov and Billard 2001). Conservation aquaculture embraces extensive aquaculture techniques and particular attention is addressed for reproduction and larval growth that are most critical phases in the aquatic animal population management (Maynard et al. 2004; Olson et al. 2004). For these reasons, in several countries fish hatcheries have been developed as first step of an effective conservation strategy (Hallermann 2004; Paragamian and Beamesderfer 2004). On this matter it is interesting the case of Washington State (USA) where salmon hatcheries compensate the natural decline of natural population producing 100 million juvenile salmons per year (Blankenship and Daniels 2004). In Idaho, Oregon and Washington the Endangered Species Act, that is program specifically drawn for wild Salmonid conservation, chiefly focuses on hatchery managing (Olson et al. 2004). In Russia, fish hatcheries are considered the principal mean of rebuilding natural population of Caspian sea sturgeons (Secor et al. 2000).

The status of freshwater bivalves rearing

In the Asia triangle shell mussel (*Hyriopsis cumingii*) is the most reared mussel species in China (Xu et al. 2011), while in much less extent crown mussel (*Cristaria plicata*) and the swan mussels (*Anodonta sp.*) are reared for pearl culture. Freshwater pearl production is also an activity well developed in Bangladesh (FAO 1986), where the species used is a local edible bivalve, the Indian freshwater mussel (*Lamellidens marginalis*). Indian freshwater mussel is traditional food for the rural human population in the Indian subcontinent and it is an ingredient of artificial feed for fish and poultry (Chakraborty et al. 2008). In North America the techniques of conservation aquaculture for freshwater fish species have been effectively transferred in bivalve conservation strategies (Neves 1999b; Henley et al. 2001; Bogan 2008; Bogan and Roe 2008). North American native bivalves are in decline and seriously threatened by the presence of non-native invasive species, Asian clam (*Corbicula fluminea*) and zebra mussel (Williams et al. 1993; Lydeard et al. 2004; Parker et al. 1998; Karatayev et al. 2007; Neves 2004; Lydeard et al. 2004). Some attempt of pearl production has been also carried out (Neves 1999a; Hua and Neves 2007). European freshwater mussels (Fig. 1) are threatened by the presence of non-native ones, principally zebra mussel and secondarily Chinese pond mussel (Cappelletti et al. 2009). In Europe, research for conservation of freshwater bivalves is focused on the recovering of freshwater pearl mussel (*Margaritifera margaritifera*) in Portugal (Reiss 2003), Great Britain (Young and Williams 1983), Germany (Buddensienk 1995), Scotland (Hastie 2006) and Sweden (Englund et al. 2008).

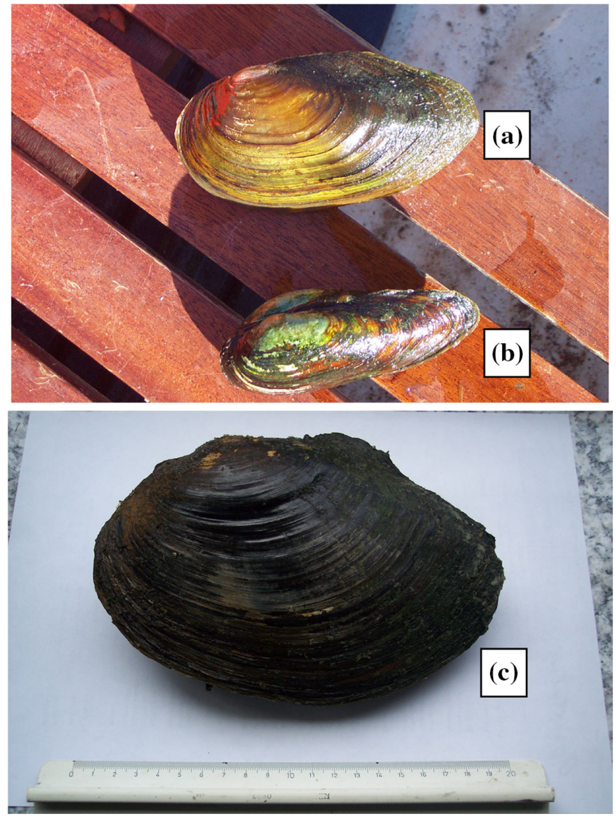

Fig. 1 Italian unionids potential candidates for freshwater mussel farming. Native species: **a** *Anodonta cygnea*, **b** *Unio mancus*; exotic species: **c** China pond mussel (*Sinanodonta woodiana*)

Bivalve nutrition in artificial conditions

In natural environment, freshwater bivalves diet is composed of phytoplankton, fine organic detritus and bacteria (Frischer et al. 2000). As regard as larval artificial nutrition, interesting results have been obtained using cultured microalgae as: *Neochloris oleoabundans*, *Nannochloropsis oculata, Phaeodactylum tricornutum*, and *Bracteacoccus grandis* (Gatenby et al. 1994; Jones et al. 2005; Wacker et al. 2002), moreover, artificial algae concentrates have been used with partial success (Nichols and Garling 2002). It is clear that the microbial water composition and sediment composition play a key role in larval nutrition as demonstrated by the success obtained especially in these recover projects that minimized the distance where mussels are moved (Raikow and Hamilton 2001).

High larval mortality is still considered the bottleneck in freshwater bivalves larval rearing (Nichols and Garling 2002; Jones et al. 2005) and possible solutions could be transferred from marine bivalve farming (Marshall et al. 2010). Efficient methods are currently used in marine bivalve larval rearing as: water disinfection, antibiotics, immunostimulants and probiotics, often as a combination of these (Fitt et al. 1992; Kesarcodi-Watson et al. 2008; Prado et al. 2010). Between these methods, probiotics is a consolidate technique already used in fish larval nutrition (Taoka et al. 2006; Fjellheim et al. 2010). Following the experience in fish larval rearing, probiotics have been successively utilized in marine bivalve larval rearing (Kesarcodi-Watson et al. 2010; Prado et al. 2010; Zhou et al. 2009). Riquelme et al. (1997) found first probiotic in bivalves, that was the bacterium *Alteromonas holoplanktis* in *Agropecten purpuratus* gonads, after that, several studies followed on marine bivalves species (Estes et al. 2004; Kesarcodi-Watson et al. 2009b). Probiotics have been successfully used in Pacific oyster (*Crassostrea gigas*) (Douillet and Langdon 1994; Gibson et al. 1998; Nicolas et al. 2004), in Chilean scallop (*Agropecten purpuratus*) (Riquelme et al. 1995; Avendano and Riquelme 1999; Riquelme et al. 2000, 2001), in scallop (*Pecten maximus*) larvae (Ruiz-Ponte

Table 1 Comparison between bacteria found in freshwater mussels and probiotics used in fish rearing

Bacteria found in freshwater mussel	Probiotics in fish
Bacillus sp. (Chittick et al. 2001)	*B. subtilis*—Indian carp, in diet (Kesarcodi-Watson et al. 2008); *Bacillus sp. B2* in scallop (*Agropecten*) (Prado et al. 2010); *B. subtilis*; *B. megaterium*; *B. polymyxa*; *B. licheniformis*—shrimp, in diet (Kesarcodi-Watson et al. 2008); *Bacillus*, commercial product (Moryartry 1997); *B. subtilis*, commercial product (Queiroz and Boyd 1998)
Streptococcus (Chittick et al. 2001)	*Streptococcus fecium* in Tilapia (Kesarcodi-Watson et al. 2008)
Aeromonas hydrophila (Chittick et al. 2001; Starliper et al. 2008) *Aeromonas sp.* (Starliper et al. 2008)	*A. hydrophila*—Rainbow trout, in diet (Balcazar et al. 2006); *A. hydrophila*—Rainbow trout, in diet (Kesarcodi-Watson et al. 2008). *A. hydrophila*—Gold fish (Irianto and Austin 2002)
Vibrio fluviatilis (Chittick et al. 2001) *Vibrio alginolyctus* (Chittick et al., 2001)	*Vibrio fluviatilis*—Raibow trout; *Vibrio sp. C33*—Scallop (*Agropecten*), oyster (*Crassostrea*) (Prado et al. 2010); *Vibrio alginolyctus*—Atlantic salmon (Balcazar et al. 2006)
Pseudomonas fluorescens (Starliper et al. 2008)	*Pseudomonas sp.* in scallop (*Agropecten*) (Prado et al. 2010)
Flavobacterium columnare (Starliper et al. 2008)	*Flaviobacterimu sp.* (Balcazar et al. 2006); *Flaviobacterimu sp.* co-culture *Chaetoceros* and *Isochrysis* (Kesarcodi-Watson et al. 2010); *Flaviobacterimu sp.* in scallop (pecten) (Prado et al. 2010)

et al. 1999) and in New Zealand green lipped mussel (*Perna canaliculus*) (Kesarcodi-Watson et al. 2009a). Also farmed gastropods, *Haliotis midae* fed a probiotic-supplemented diet showed improved survival and growth rate (Macey and Coyne 2005).

Considering that the gastrointestinal tract of mollusks hosts a large number of microorganisms closely influenced by those found in the natural environment, an ideal probiotic is a microorganism naturally occurring in the healthy bivalve that should be isolated and successively inoculated in the water with bivalve larvae (Prado et al. 2010). Unfortunately, until this moment the studies on freshwater microbial flora are scarce and they are primarily focused on the risks for human health (Starliper et al. 2008; Chittick et al. 2001; Langdon et al. 2006; Starliper 2008; Teplitski et al. 2009) and natural feeding (Johnson et al. 1993; Frischer et al. 2000). On the other side, considering the probiotics in marine bivalves, the list of those currently used is wide (Kesarcodi-Watson et al. 2010; Prado et al. 2010) considering also that symbiotic microbial flora interacts with cultured algae (Nicolas et al. 2004; Schulze et al. 2006; Avendano and Riquelme 1999; Salvesen et al. 2000). Kesarcodi-Watson et al. (2009a) developed an interesting bioassay, based on the use of tissue culture dishes, useful to select bacterial strains as probiotics in New Zealand green lipped mussel larval nutrition. Pilot tests carried out under hatchery conditions, confirmed the usefulness of this screening method that could be used in freshwater mussel. To suggest a list of potential probiotics candidates for freshwater mussel larvae, a comparison between the bacteria found in the intestinal tract of unionids with symbiotic bacteria or probiotics already found and used in fish larval nutrition has been proposed (Table 1). This table can be used as a reference point for future study on probiotics for freshwater mussels. Another approach to the study of probiotics is focused not on reared animals but on the farm environment, in particular the hatchery. This is particularly interesting because it can be used as complementary to previous ones. Skjermo and Valdestein (1999) successfully proposed this method based on the microbiological control of water in salmon farming and called it "matured water" method.

The future perspectives

Larval nutrition is the most important phase of the freshwater bivalve farming to be clarified in the next years for optimal development of this sector of aquaculture. Following the example of marine bivalves, probiotics and aquatic microbial control of water in the hatcheries will play a key role also in freshwater bivalves. In general terms, to promote freshwater bivalve farming, the diversification of production and finalities is a crucial issue and the researchers need to explore new applications of bivalves rearing taking in consideration bivalve potentialities. Conservation aquaculture and pearl production are not sufficient to guarantee relevant research and future economic investments, other applications must be investigated as integrated productions, bioindication studies and protein source for fish feeds, and finally education projects. Moreover, utilization of non-native bivalves must be investigated, to transform (partially) this threat in an opportunity obtaining at the same time a method to control their expansion. Bivalves, particularly mussels, are highly efficient filter feeders; they can filter 30–60 times their volume of water per hour and not only deplete the plankton from the water column, but also accumulate nutrients. This filtration activity has negatively affected North America freshwater systems, in the case of zebra mussel (Roditi et al. 1996), but there is a positive aspect that represents a great opportunity in bioremediation projects. European unionids have been used for integrated projects of aquaculture (MacDonald and Robinson 2011); Prins and Smaal (1994) showed that blue mussel (*Mytilus edulis*) strongly contributed to nitrogen remineralization in Oosterschelde estuary, Neterland; a biofiltration system based on *Corbicula fluminea* has been proposed as water treatment to remove phosphorus-containing material from agricultural wastewater streams (Riley 2008). Chilean freshwater mussels (*Diplodon chilensis*) have been successfully used as a biocontrol system in salmon farming eutrophication (Soto and Mena 1999).

Another application for the use of freshwater mussels is the utilization of freshwater mussel meal in fish nutrition. Blue mussels are usually used in lobster (*Homarus spp.*) nutrition as feed attractants and in the fish broodstock nutrition (Myers and Tlusty 2009). Following the example of blue mussel utilization in rainbow trout (*Oncorhynchus mykiss*) artificial diets (Berge and Austreng 1989), freshwater mussel meal has been used as attractant in ornamental fish nutrition and in artificial feed for rainbow trout (Sicuro et al. 2010), but considering the low price of fish meal, that is the main ingredient for fish feed in aquaculture, the best perspectives for freshwater meal use in fish nutrition are in ornamental fish, broodstock and fish larval nutrition. This fact represents an opportunity economically suitable for freshwater mussel meal utilization and also non-native species can be also investigated for these applications. Looking at recent evolution of aquaculture, it is possible to see several cases where non-native species have become development opportunity, as Manila clam in Italy and Pacific oyster in France. Similarly, the utilization of non-native freshwater bivalves could reduce their future expansion. Finally freshwater mussels, for their rusticity and for their peculiar biological cycle that includes a parasitic larval stage, are ideal tools for education projects on freshwater ecosystems in primary and secondary schools.

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